MATCHING ANTISYMMETRIC ARC OPTICS TO SYMMETRIC INTERACTION REGION *

J.L. Abelleira, EPFL, Lausanne, Switzerland & CERN, Geneva, Switzerland
F. Zimmermann, CERN, Geneva, Switzerland

Abstract

Considering a generic double-ring collider, we discuss the matching from an antisymmetric optics in the arcs to a symmetric optics in the interaction region (IR) by means of an antisymmetric matching section. As an example, we present an application to the LHC, for which a symmetric IR with extremely flat beams is under study.

INTRODUCTION

A proposed future IR for LHC [1] with extremely flat beam optics ($\beta_x/\beta_y = 100$) is based on a symmetric layout. In particular it motivates providing the same optics for the two beams, both before and after the interaction point (IP), so as to more easily fulfil the phase-advance requirements for a local chromatic correction in the vertical plane. This differs from the present antisymmetric design LHC optics, where the optics for the x plane of one beam (or on one side of the IP) is equal to the optics for the y plane of the other beam (or side).

The symmetric IP optics, with $\beta_x^* \gg \beta_y^*$ is realized through a novel magnetic element on either side of the IP, a "double half quadrupole" [2]. This special magnet provides a quadrupolar field of opposite sign for the two counter-rotating proton beams, transversely separated thanks to a crossing angle, within a common beam pipe aperture, so that both beams are focused in the vertical plane.

The small values of β_y^* considered for extremely flat-beam collisions (a few cm) cannot be reached for a standard quadrupole magnet with the same field gradient for both beams in a common aperture, as for the nominal LHC, since in that case the vertical beta function of one of the two beams (or on one side of the IP) would become so large as to render chromatic correction impossible using available sextupole strengths.

SYMMETRIC IR

A symmetric IR is characterized by the same parameters of the normalized quadrupole focusing strength k [m^{-2}] on both sides of the IP and for both beams. That is, for each beam, $k(s) = k(-s)$; and $k^1(s) = k^2(s)$, where the superindex refers to the beam. Such optics exhibits the following properties for both beams:

$$\beta_x(s) = \beta_x(-s)\,;\alpha_x(s) = -\alpha_x(-s)\;, \quad (1)$$

$$\beta_y(s) = \beta_y(-s)\,;\alpha_y(s) = -\alpha_y(-s)\;. \quad (2)$$

The optics for the two beams are related as follows.

$$\beta_x^1(s) = \beta_x^2(s)\,;\alpha_x^1(s) = \alpha_x^2(s)\;, \quad (3)$$

$$\beta_y^1(s) = \beta_y^2(s)\,;\alpha_y^1(s) = \alpha_y^2(s)\;. \quad (4)$$

By contrast, the present LHC IRs features an antisymmetric optics, with $k(s) = -k(-s)$; and $k^1(s) = -k^2(s)$, where for each beam

$$\beta_x(s) = \beta_y(-s)\,;\alpha_x(s) = -\alpha_y(-s)\;, \quad (5)$$

$$\beta_y(s) = \beta_x(-s)\,;\alpha_y(s) = -\alpha_x(-s)\;. \quad (6)$$

and where the following relations hold between the two beams:

$$\beta_x^1(s) = \beta_y^2(s)\,;\alpha_x^1(s) = \alpha_y^2(s)\;, \quad (7)$$

$$\beta_y^1(s) = \beta_x^2(s)\,;\alpha_y^1(s) = \alpha_x^2(s)\;. \quad (8)$$

Figs. 1 and 2 show the antisymmetric properties. The proposed new symmetric IR has to be matched to the arc optics. The latter has approximately the same antisymmetry properties as those defined by the relations (5), (6), (7) and (8); the only difference being due to the weak focusing of the bending magnets.

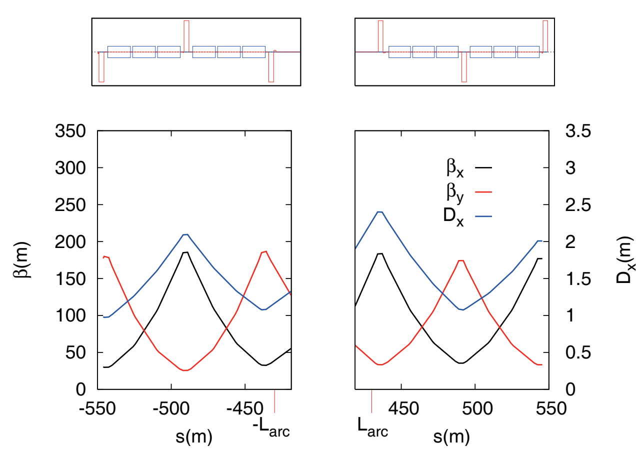

Figure 1: First arc cell on either side of IP1 in the present LHC for Beam 1. Dipoles are shown in blue and quadrupoles in red.

SIMPLIFYING THE MATCHING

We denote by L_{IR} and L_{ARC} the distances from the interaction point (IP) to the end of the IR and to the beginning of the arc, respectively. In the particular case of the

* Work supported by the European Commission under the FP7 Research Infrastructures project EuCARD, grant agreement no. 227579.

ISBN 978-3-95450-122-9

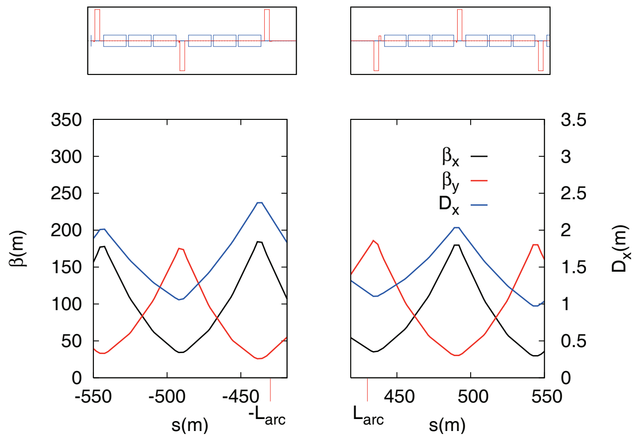

Figure 2: First arc cell on either side of IP1 in the present LHC for Beam 2.

extremely-flat IR [3], $L_{IR} = 165$ m, and $L_{ARC} = 434$ m for the LHC. As a result of the present LHC arcs antisymmetry, different matching sections (MSs) are needed on the two sides of the IP [3] for the following reasons: First, the matching is performed from a symmetric optics around the IP, over $\pm L_{IR}$, to an antisymmetric optics at location $\pm L_{ARC}$, which introduces different conditions one the two sides of the IP. Second, the dispersion has a non-zero slope at the IP (implying dispersion across the IR), e.g. as a necessary ingredient for a local chromatic correction. Separator dipole magnets generate an antisymmetric dispersion, that is

$$D_x(-s) = -D_x(s) \; , \tag{9}$$

$$D'_x(-s) = D_x(s) \; . \tag{10}$$

Therefore, the dispersion has different sign in $\pm L_{IR}$ while the dispersion in the arcs is positive at both sides.

Two different MSs on each side of the IP also imply two different MSs for the two beams on one side of the IP.

On the other hand, modifying one or several arc cells (Fig. 1) would allow establishing the properties (1), (2), (3) and (4) over the extended range $\pm L_{ARC}$, and, thereby, allow the symmetric matching.

The objective of this study is to show how to match from a symmetric to an antisymmetric optics.

MODIFICATION OF ONE LHC CELL

If only the existing weak "trim quadrupoles" of the first arc cell (MQTLI.11, MQT.12, MQT.13) are varied to meet the conditions $\beta_x(L_{ARC}) = \beta_y(L_{ARC})$, $\alpha_x(L_{ARC}) = \alpha_y(L_{ARC})$, $\beta_x(-L_{ARC}) = \beta_y(-L_{ARC})$, $\alpha_x(-L_{ARC}) = \alpha_y(-L_{ARC})$, we get the results in Table 1. As $\beta_{x,y}(-L_{ARC}) \neq \beta_{x,y}(L_{ARC})$ and $\alpha_{x,y}(-L_{ARC}) \neq -\alpha_{x,y}(L_{ARC})$, we conclude that the trim quadrupoles do not give enough flexibility to "symmetrize" one arc cell, and we need to individually power the main quadrupole magnets of the first arc cell (MQ.11, MQ.12 and MQ.13 at both sides). The corresponding optics is shown in Fig. 3, while the numerical values for Beam 1 on both left and right sides of the IP are shown in Table 2.

Table 1: Optics parameters at the beginning of the arc for one arc cell modified by changing the trim quadrupoles only

	$-L_{ARC}$	L_{ARC}
$\beta_{x,y}$ [m]	136.2	145.1
$\alpha_{x,y}$	−0.71	0.60
D_x [m]	2.1	2.5
D'_x	0.02	−0.01

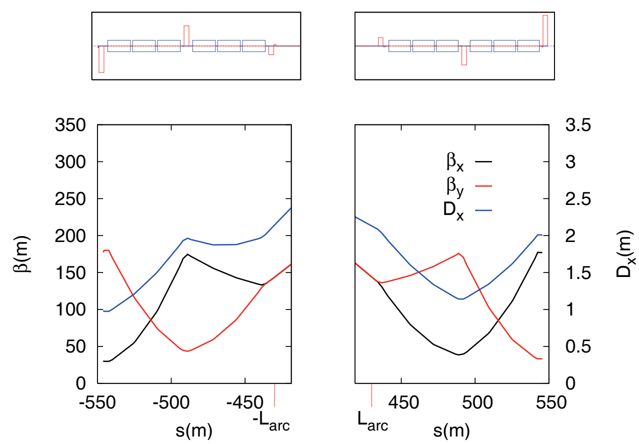

Figure 3: Modified optics of the first arc cell on each side of the IP (Beam 1), for matching to a symmetric optics.

Table 2: Optics parameters at the beginning of the arc for one arc cell modified by changing the strength of the main quadrupoles

	$-L_{ARC}$	L_{ARC}
$\beta_{x,y}$ [m]	137.5	137.5
$\alpha_{x,y}$	−0.68	0.74
D_x [m]	2.1	2.1
D'_x	0.02	−0.01

The optics is almost symmetric or "quasi-symmetric": the values in Table 2 approximately fulfil the relations (1) and (2).

We note that the optics does not meet the conditions (9) and (10) because the arc dispersion has the same sign on both sides. A matching from (9, 10) within $\pm L_{IR}$ to the dispersion in the arcs by a symmetric MS could be achieved by imposing one of the following two sets of conditions:

$$D_x(\pm L_{IR}) = D'_x(\pm L_{IR}) = D'_x(\pm L_{ARC}) = 0; \tag{11}$$

or

$$D_x(\pm L_{ARC}) = 0; D'_x(L_{ARC}) = D'_x(-L_{ARC}); \tag{12}$$

These conditions are sketched in Fig. 4.

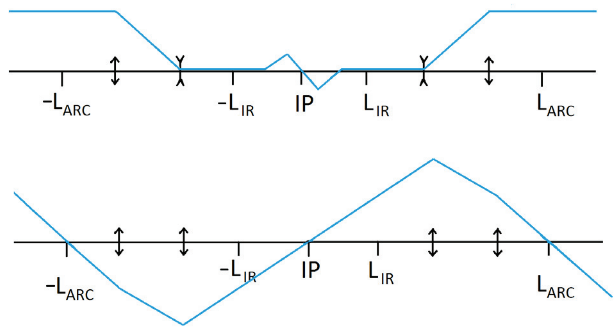

Figure 4: Sketch for the conditions over dispersion matching: (11) [top] and (12) [bottom].

MODIFICATION OF TWO LHC CELLS

We have just seen that by modifying a single cell, the β-functions can be made to be equivalent on both sides of the IP, but this is not the case for the dispersion. Therefore, we have explored whether by modifying two cells we can make the matching on either side of the IP fully identical. The two arc cells have been modified by varying the strengths in quadrupoles MQ.14 and MQ.15 in addition to those varied in the previous section. Matching to (11) and (12) has been attempted. For the right side, if $D_x(L_{ARC}) = 0$ is forced, the α-values at the beginning of the arc are inverted between the planes, $\alpha_x(L_{ARC}) \sim -\alpha_y(L_{ARC})$, and the same has been observed for the left side, namely $\alpha_x(-L_{ARC}) \sim -\alpha_y(-L_{ARC})$. Imposing $D'_x(L_{ARC}) = 0$ yielded $\alpha_x(L_{ARC}) = \alpha_y(L_{ARC})$, on the right side, while on the left side the α-functions were again inverted. Finally, as in the case for one modified arc cell, a matching to $\beta_x(L_{ARC}) = \beta_y(L_{ARC})$, $\alpha_x(L_{ARC}) = \alpha_y(L_{ARC})$ was tried, to explore if there was a significant improvement. The result of the matching with modifications in two arc cells is shown in Fig. 5, and the values for the optics parameters are summarized in Table 3. These results are better than for one arc cell. In fact, the matching of the β- and α-functions is almost exact, but as with the case of one modified arc cell, it was not possible to fulfil the dispersion conditions (9) and (10).

Table 3: Optics parameters at the beginning of the arc for two modified arc cells

	$-L_{ARC}$	L_{ARC}
$\beta_{x,y}$ [m]	137.5	137.5
$\alpha_{x,y}$	-0.74	0.74
D_x [m]	1.9	2.1
D'_x	0.02	-0.01

CONCLUSIONS

Some novel ideas to the problem of matching a new symmetric IR to existing antisymmetric arcs have been discussed and illustrated, for the example of the LHC. A perfect symmetric matching is not possible due to the dispersion, but an individual powering of some (three or five) arc quadrupoles has been proposed as a concept to make at least similar the different matching sections at both sides of the IP and for both beams.

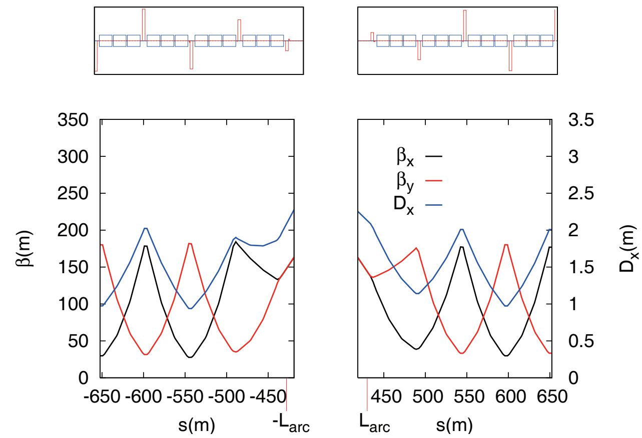

Figure 5: Modified optics of the two first arc cells on each side of the IP (Beam 1), for matching to a symmetric IR optics.

For a future machine featuring only symmetric IRs (for example, HE-LHC [4] or VHE-LHC [5]) the best approach will be to generate a symmetric optics also in the arcs [6], e.g. by creating opposite gradients in the quadrupoles for the two beams. A scheme featuring relation (11) would solve the issue of the dispersion matching.

If HE-LHC were to be built as a $p\bar{p}$ collider, the arc optics would be symmetric, as it has been the case in many past colliders. In this case, due to the opposite sign of the charge, the two beams would experience the same focusing forces.

REFERENCES

[1] J.L. Abelleira, at EUCARD Annual Meeting, April 25-27, 2012, Warsaw, Poland.

[2] J.L. Abelleira et al, Proc. IPAC'12 New Orleans, U.S.A. p. 118.

[3] J.L. Abelleira et al, "LHC Optics with Crab-Waist Collisions and Local Chromatic Correction ". Proc. IPAC'13 Shanghai, China.

[4] E. Todesco, F. Zimmermann (eds.), Proc.EuCARD-AccNet-EuroLumi Workshop: The High-Energy Large Hadron Collider, Malta, Oct. 2010, CERN-2001-003.

[5] L. Rossi and F. Zimmermann, contributions to joint EuCARD-HiLumi-Snowmass Workshop on "Frontier Capabilities for Hadron Colliders". February 22-23; 2013, CERN, Switzerland.

[6] J.L. Abelleira, contribution to joint EuCARD-HiLumi-Snowmass Workshop on "Frontier Capabilities for Hadron Colliders." February 22-23; 2013, CERN, Switzerland.

ISBN 978-3-95450-122-9